Electrical Fundamentals
Module 3: Parallel Circuits

PREPARED BY

IAT Curriculum Unit

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Module 3: Parallel Circuits

Module Objectives
Upon completion of this module, students should be able to:

1. Explore the idea of a parallel circuit.
2. Understand how to draw a circuit diagram of a parallel circuit.
3. State the voltage, current, resistance, and power characteristics of a parallel circuit.
5. Use a multimeter to measure the potential differences (voltages), currents and resistance of parallel circuits.
6. Apply Ohm’s Law to calculate resistance, voltage and current in parallel circuits.
8. Recognize some basic applications of parallel circuits

Module Contents
1. Introduction
2. Wiring and Measuring Voltage, Current, and Resistance in a Parallel Circuit
3. Parallel Circuit Calculations
4. Kirchhoff’s Current Law
5. Practical Tasks
3.1 Introduction

A parallel circuit is a circuit that has two or more paths (or branches) for current flow.

The tracks on railway lines run side by side in parallel. A parallel circuit is similar. The different components are connected on different wires. If you follow the circuit diagram shown in Fig 3.1 from one side of the cell to the other, you can only pass through all the different components if you follow the branches.

In a parallel circuit shown in Fig 3.2, if a lamp 'blows' or a component is disconnected from one parallel wire, the components on different wires keep working. Unlike a series circuit, the lamps stay bright if you add more lamps in parallel.

3.2 Wiring and Measuring Voltage, Current, and Resistance in a Parallel Circuit

Materials: four insulated copper wires, one multimeter, two 1.5-volt D cells, two dry cell holders, one 100-Ω resistor, one 220-Ω resistor, four alligator clips

Procedure:

1. Build a parallel circuit as shown in Fig 3.3 using two dry cells and two resistors, wiring the two dry cells in parallel and wiring the two resistors in parallel. Connect the 220-ohm resistor on the far right.

   Note: To wire dry cells in parallel, connect the positive ends to each other then connect the negative ends to each other.
2. Dial to the lowest DC V (direct current voltage) setting. Measure the dry cell on the left first. Attach the multimeter across the dry cell to measure the voltage, making sure to connect the red and black leads of the meter to the positive and negative terminals on the dry cell, respectively. Enter your results in the Parallel Circuit Data Table shown below.

<table>
<thead>
<tr>
<th>Reading</th>
<th>Measurement</th>
<th>Voltage (V)</th>
<th>Current (A)</th>
<th>Resistance (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dry Cell 1</td>
<td></td>
<td>Should be zero</td>
<td>Do not measure</td>
</tr>
<tr>
<td>2</td>
<td>Dry Cell 2</td>
<td></td>
<td>Should be zero</td>
<td>Do not measure</td>
</tr>
<tr>
<td>3</td>
<td>100-Ω Resistor</td>
<td></td>
<td>$R_1$:</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>220-Ω Resistor</td>
<td></td>
<td>$R_2$:</td>
<td></td>
</tr>
</tbody>
</table>

3. Repeat the voltage measurement across the second dry cell. Record the voltage.

4. Repeat the voltage measurement across each of the resistors, starting with the one on the left. Enter the resistor voltages.

5. For current measurement, break the circuit as shown in Fig 3.4 to perform reading 1 and close it by connecting the red and black leads from the meter. Change the multimeter setting to the most appropriate DC amps (A) scale (200 mA). Enter the current in amps, which requires a conversion from mA (slide the decimal three places to the left to convert from mA to A). Insert the meter into the circuit as shown in the diagram for readings 2 through 4. Record your current values.
6. Use the appropriate version of Ohm's Law to calculate the two resistor resistances ($R_1$ and $R_2$). Calculate the resistance of the first resistor ($R_1$) using the Dry Cell 2 voltage and the reading 2 current (reading 1 is the total current). Calculate the resistance of the second resistor ($R_2$) using the Dry Cell 2 voltage and the reading 4 current.

<table>
<thead>
<tr>
<th>$R_1$ (calculated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_2$ (calculated)</td>
</tr>
</tbody>
</table>

7. Change the multimeter setting to the most appropriate ohms (Ω) scale (less than 500 ohms for small resistors). DISCONNECT the resistors for the resistance measurements. Zero the meter by touching the two probes together before each measurement. Measure resistance across each of the two resistors. Record the answers in the data table.
3.3 Hands-On Parallel Circuit Measurement Questions

Use the reciprocal formula to calculate the total resistance \((R_T)\) of the parallel circuit you built. Report all answers to two significant figures.

\[
R_{Total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}
\]

<table>
<thead>
<tr>
<th>(R_{Total})</th>
</tr>
</thead>
<tbody>
<tr>
<td>()</td>
</tr>
</tbody>
</table>

1. Calculate total current \((I_T)\).

<table>
<thead>
<tr>
<th>(I_{T1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>()</td>
</tr>
</tbody>
</table>

2. Check Ohm’s Law as it applies to each of the two parallel circuit paths you just built and measured. Using your measured values, does the total voltage (the voltage across one dry cell) equal the current times the resistance for each circuit path? In other words, does

\[V_T = I_1 R_1\]

and does

\[V_T = I_2 R_2\]

(within a 5 percent margin of error)?

____________________________
____________________________
____________________________
____________________________
____________________________
____________________________
3. How does the total voltage (the voltage of the dry cell) compare with each resistor voltage?

a. The total (dry cell) voltage is higher than the voltage across each resistor.

b. The total (dry cell) voltage is lower than the voltage across each resistor.

c. The total (dry cell) voltage is the same as the voltage across each resistor.

4. Does the current entering a circuit junction (reading 1) equal the sum of the currents leaving the junction (reading 2 + reading 4)?
3.4 Parallel Circuit Calculations

Parallel circuit branches are independent of each other as shown in Fig 3.5, each connected directly to the battery, receiving its full charge. For parallel circuits the total voltage across each circuit path equals the voltage of the battery. Thus, if one branch is opened (turned off) or failed, the others will continue to work. This is one reason our homes, businesses, cars, and various electronic devices are wired in parallel.

The formulas for calculating voltage, current and resistance in parallel circuits are a little different from those for series circuits. The formula for resistance is referred to as the reciprocal formula. Can you guess why? (Reciprocal means one over ...)

<table>
<thead>
<tr>
<th>Voltage</th>
<th>( V_{Total} = V_1 = V_2 = V_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>( I_{Total} = I_1 + I_2 + I_3 )</td>
</tr>
<tr>
<td>Resistance</td>
<td>( R_{Total} = \frac{1}{1/R_1 + 1/R_2 + 1/R_3} ) (the reciprocal formula)</td>
</tr>
</tbody>
</table>

Ohm’s Law remains \( V = I \cdot R \), or \( V_T = I_T \cdot R_T \), and \( V_1 = I_1 \cdot R_1 \) for circuit path 1, etc.

**Total Resistance in Series vs. Parallel Circuits**

In series circuits the total resistance equals the sum of the individual resistances. But in parallel circuits you're in for a surprise. The total resistance will be less than the lowest circuit path resistance!
Example:

You have a dry cell with a voltage of 6 Volts ($V_t$) connected to three light bulbs wired in parallel to each other as shown here. The three bulbs have resistances of 400, 500, and 600 ohms ($R_1$, $R_2$, and $R_3$), respectively.

Calculate:

1. Total resistance ($R_t$),

$$R_{Total} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_{Total} = \frac{1}{\frac{1}{400 \, \Omega} + \frac{1}{500 \, \Omega} + \frac{1}{600 \, \Omega}}$$

$$R_{Total} = \frac{1}{0.0025 + 0.0020 + 0.0017} \, \Omega$$

$$R_{Total} = \frac{1}{0.0062} \, \Omega$$

$$R_{Total} = 161 \, \Omega$$

2. Individual currents ($I_1$, $I_2$, and $I_3$)

Remember, the total voltage ($V_T$), which is the voltage of the source dry cell, equals the voltage for each path. In other words, $V_T = V_1 = V_2 = V_3$.

$$I_1 = \frac{V_1}{R_1}$$

$I_1 = 6 \, \text{V} / 400 \, \Omega$

$I_1 = 0.015 \, \text{A} \, (\text{or} \, 15 \, \text{mA})$

$$I_2 = \frac{V_3}{R_3}$$
I_2 = 6 V / 500 Ω

I_2 = 0.012 A (or 12 mA)

I_3 = V_3 / R_3

I_3 = 6 V / 600 Ω

I_3 = 0.010 A (or 10 mA)

3. Total current (using the sum of the individual currents)

I_t = I_1 + I_2 + I_3

I_t = 0.015 A + 0.012 A + 0.010 A

I_t = 0.037 A

4. Total current (using Ohm's law)

I_t = V_t / R_t

I_t = 6 V / 161 Ω

I_t = 0.037 A (or 37 mA)

5. Is total current the same using both methods of calculation?

Yes, I_t = 0.037 A using both methods of calculation!

Example:

Two resistors are connected in parallel as shown in Fig 3.6. Find the total resistance of the circuit.

1/R_{tot} = 1/R_1 + 1/R_2 = 1/(1 Ω) + 1/(4 Ω) = 5/(4 Ω)

R_{tot} = 0.8 Ω

Two resistors connected in parallel
Fig 3.6
Example:

Given the circuit shown in Fig 3.7

   a. Find the total resistance, $R_{tot}$.
   b. Find the total current, $I_{tot}$.
   c. Find voltage across each resistor.
   d. Find the current through each resistor.

a. $1/R_{tot} = 1/R_1 + 1/R_2 = 1/(15) + 1/(45)$
   $R_{tot} = 11.25 \, \Omega$

b. $R_{tot} = V_{tot}/I_{tot}$
   $I_{tot} = V_{tot}/R_{tot} = (10 \, V)/(11.25 \, \Omega)$
   $I_{tot} = 0.889 \, A$

c. $V_{tot} = V_1 = V_2 = 10 \, V$

d. $R = V/I$

   $I_1 = V_1/R_1 = (10 \, V)/(15 \, \Omega) = 0.667 \, A$
   $I_2 = V_2/R_2 = (10 \, V)/(45 \, \Omega) = 0.222 \, A$

3.5 Power Calculations in Parallel Circuits

Power dissipation in a parallel circuit is the same as that of a series circuit. Therefore, the total power dissipated ($P_T$) in a parallel circuit equals the sum of the power dissipated by the individual branch resistors or the product of total current ($I_T$) and the source voltage ($V_T$)

\[ P_T = V_T \times I_T \]
### 3.6 Kirchhoff’s Current Law

- If you have water flowing into and out of a junction of several pipes, water flowing into the junction must equal water flowing out.
- The same applies to electric currents as shown in Fig 3.8a.

That is, \( I_1 + I_2 + I_3 + I_4 = 0 \).

- Note that for this formula to work, some of the currents in the diagram must have negative values.
- If a current does have a negative value, all this means is that the current is in the direction opposite to the arrow as drawn.

#### Example

If \( I_1 = 900 \text{mA} \), \( I_2 = -600 \text{mA} \), and \( I_3 = 600 \text{mA} \),

What is \( I_4 \)?

**Answer, \( I_4 = -900 \text{mA} \)**

#### Exercise:

In the circuit diagram shown in Fig 3.8b, find the total current \( I \).

\[
\begin{align*}
\text{Fig 3.8a} & \\
\text{Fig 3.8b} & \\
\end{align*}
\]
Practical Task

Equipment:

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity &amp; Electronics Constructor EEC470.</td>
<td>1</td>
</tr>
<tr>
<td>Basic Electricity and Electronics Kit EEC471-2</td>
<td>1</td>
</tr>
<tr>
<td>Power supply unit 0 to 20 V variable dc regulated.</td>
<td>1</td>
</tr>
<tr>
<td>Multimeters</td>
<td>2</td>
</tr>
</tbody>
</table>

Procedure

1. Choose the 220 Ω and 470 Ω from electronics kit. Connect them in parallel. Calculate and record the total values in Table 1.

2. Use a multimeter to measure the total resistance and record it in Table 1.

<table>
<thead>
<tr>
<th>Calculated $R_T$ in Ω</th>
<th>Measured $R_T$ in Ω</th>
<th>The difference in Ω</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1
3. Construct the circuit shown in Fig 3.9

![Fig 3.9: Circuit Diagram](image)

4. Ask your teacher to check the connection before you turn the power supply ON.

5. Calculate the value of the voltages $V_1$ and $V_2$ across each resistor.

6. Measure the voltages $V_1$ and $V_2$ record the values in Table 2.

7. Calculate the currents $I_1$ and $I_2$. 
8. Measure the currents $I_1$ and $I_2$. Record the values in Table 2.

9. Calculate the values of the resistances $R_1$ and $R_2$ using Ohm’s law and record the values in Table 2.

\[
\begin{array}{|c|c|c|c|c|}
\hline
V_1 & V_2 & I_1 & I_2 & R_1 = \frac{V_1}{I_1} & R_2 = \frac{V_2}{I_1} \\
\hline
\end{array}
\]

Table 2

**Conclusion**

1. Compare the values of $V_T$, $V_1$ and $V_2$.

2. Show that the total current $I_T$ is equal to the sum of the currents $I_1$ and $I_2$. 
**Home Assignment**

1. Calculate the total resistance of two resistors in parallel when \( R_1 = 20\, \Omega \) and \( R_2 = 80\, \Omega \).

2. Refer to the circuit shown in Fig 3.10

![Fig 3.10](image)

a) Calculate
   - The total resistance
   - The total current
   - The current in each branch
b) Show that the total current is equal to the sum of currents $I_1$ and $I_2$

2. Refer to the circuit shown in Fig 3.11

24 V

Fig 3.11

<table>
<thead>
<tr>
<th>$I_1$</th>
<th>$I_2$</th>
<th>$I_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 Ω</td>
<td>220 Ω</td>
<td>470 Ω</td>
</tr>
</tbody>
</table>

a) Calculate

- The total resistance

- The total current

- The current in each branch
b) Show that the total current is equal to the sum of currents $I_1$ and $I_2$

Review Questions:

Choose the letter that best completes the statement:

1- A parallel circuit has:
   (a) One pathway for current flow.
   (b) Two pathways for current flow
   (c) Three pathways for current flow
   (d) as many pathways for current flow as there are loads connected in parallel

2- The voltage applied to a parallel circuit is always:
   (a) Divided among each of the loads.
   (b) Divided equally among each of the loads.
   (c) Different across each of the loads
   (d) The same across each of the loads and equal in value to the applied voltage.

3- The total resistance of a parallel circuit:
   (a) increases as more loads are connected in parallel.
   (b) decreases as more loads are connected in parallel
   (c) is less than the resistance of the smallest load resistor.
   (d) both b and c

4- In a parallel circuit, the current flow through each load resistor:
   (a) is exactly the same value.
   (b) varies according to the resistance value of the resistor
   (c) is greater for resistors with low resistance values.
   (d) both b and c

5- Adding parallel branches to a circuit always:
   (a) decreases total conductance
   (b) increases total resistance
   (c) decreases total current
   (d) decreases total resistance
6- Technician A says the total power dissipation of a dc series or parallel circuit is always the sum of the power dissipated by the individual resistors. Technician B says this rule applies only to the parallel circuit. Who is correct?
   (a) Technician A only                     (c) both Technician A and Technician B
   (b) Technician B only                     (d) neither Technician A nor technician B

7- The sum of all branch currents in a parallel circuit must be ———— the total source current.
   (a) greater than                        (b) less than                         (c) equal to                (d) not equal to

8- With 12 V applied across five 6-Ω resistors in parallel, the total current equals —
   (a) 10 A                               (b) 6 A                              (c) 4 A                      (d) 2 A

9- With two resistances connected in parallel, if each dissipates 2 W, the total power supplied by the voltage source equals .
   (a) 4 W                                 (b) 6 W                               (c) 8 W                      (d) 10 W

10- With resistances of 50 Ω, 100 Ω, 1.4 kΩ, and 1 MΩ in parallel, RT is:
    (a) less than 50 Ω                    (c) about 1.5 kΩ
    (b) more than 1 MΩ                    (d) about 2 MΩ

11- With two resistances connected in parallel:
   (a) the current through each must be the same .
   (b) the voltage across each must be the same .
   (c) their combined resistance equals the sum of the individual values
   (d) both b and c

12- Resistors or 10 Ω and 30 Ω are connected in parallel to a 120-V supply. The current flow through the 30-Ω resistor would be:
    (a) 12 A                               (b) 8 A                                (c) 4 A                      (d) 3 A

13- A three-branch parallel resistor circuit is connected to a 6-V source. The branch currents are 1.2 A, 800 mA, and 250 mA, respectively. The total current is:
    (a) less than 1.2 A                     (c) about 1050 mA.
    (b) less than 800 mA.                   (d) about 2.25 A
14- Three resistors of $10 \, \Omega$, $25 \, \Omega$ and $50 \, \Omega$, respectively, are connected in parallel to a $100\, \text{V}$ source. Which resistor would dissipate the most power?
   (a) The $10 \, \Omega$ resistor             (c) the $50\, \Omega$ resistor
   (b) The $25 \, \Omega$ resistor              (d) It would be the same for all resistors

15- Four lamps of equal resistance are connected in parallel to a $120\, \text{V}$ source. If the total current supplied to the lamps is $3\, \text{A}$, the resistance of each lamp is
   (a) $10 \, \Omega$                          (b) $20 \, \Omega$                            (c) $30 \, \Omega$                           (d) $160 \, \Omega$

16- Technician A says the voltage drop across each resistor in a parallel circuit is the same, even though the resistance values are different. Technician B says the current through each resistor in a parallel circuit will be different if the resistance values are different. Who is correct?
   (a) Technician A only                   (c) both Technician A and Technician B
   (b) Technician B only                    (d) neither Technician A nor Technician B

17- Four resistors, $1\, \text{k}\, \Omega$ each, are connected in parallel. This group is connected to a $9\, \text{V}$ source.
   Part 1: The combined resistance of the group would be:
   (a) $100\, \Omega$                          (b) $150\, \Omega$                            (c) $200\, \Omega$                           (d) $250 \, \Omega$
   Part 2: The current in the line leading to the group of resistors would be
   (a) $12\, \text{mA}$                        (b) $18\, \text{mA}$                            (c) $36\, \text{mA}$                           (d) $500\, \text{mA}$
   Part 3: The current flow through each resistor would be:
   (a) $3\, \text{mA}$                        (b) $9\, \text{mA}$                             (c) $125\, \text{mA}$                          (d) $250\, \text{mA}$

18- With an open in one of the branches of a parallel circuit, the total resistance is
   (a) increases                           (b) decreases                              (c) is zero                              (d) is infinite
19- The voltage across an open component in a parallel circuit is always equal to:
(a) the source voltage (c) the lowest circuit voltage
(b) the dropped voltage (d) zero

20- The total current to a parallel circuit is measured and found to be below its normal value. Technician A says this indicates a short in one of the branches. Technician B says this indicates an open in one of the branches. Who is correct?
(a) Technician A only (c) both Technician A and Technician B
(b) Technician B only (d) neither Technician A nor Technician B

21- With a short in one of the branches of a parallel circuit:
(a) the voltage source is shorted out.
(b) the voltage source will deliver its maximum current flow.
(c) the total circuit resistance drops to near zero resistance
(d) all of these

22- Technician A says, in a parallel circuit, a shorted resistor shorts out the entire circuit. Technician B says this can burn out the power supply unless the circuit is protected by a fuse or a circuit breaker. Who is correct?
(a) Technician A only (c) both Technician A and Technician B
(b) Technician B only (d) neither Technician A nor Technician B

23- You are taking a voltage measurement across the branch of a parallel circuit when you accidentally short the two meter test leads together. What happens?
(a) applied voltage shorts out (c) fuse blows
(b) total current increases (d) all of these

24- Technician A says the current is always less on the return line that connects the voltage source to the parallel branches. Technician B says the current is the same on both sides of the main lines that connects the voltages source to the parallel branches. Who is correct?
(a) Technician A only (c) both Technician A and Technician B
(b) Technician B only (d) neither Technician A nor Technician B